Chapter 4
Learning Parametric Designing

Marc Aurel Schnabel
The Chinese University of Hong Kong, Hong Kong

ABSTRACT

Parametric designing, its instruments, and techniques move architectural design education towards novel avenues of deep learning. Akin to learning and working environments of engineering and manufacturing, it offers similar advantages for architects. Yet it is not as simple as using another tool; parametric designing fundamentally shifts the engagement with the design problem. Parametric designing allows architects to be substantially deeper involved in the overall design and development process extending it effectively beyond production and lifecycle. Leaning parametric design strategies enhance architects' critical engagement with their designs and their communication. Subsequently, the computational aid of parametric modelling alters substantially how and what students learn and architects practice.

INTRODUCTION

Parametric design techniques offer obvious advantages for engineering and manufacturing processes, now architects have emerged to apply these methods in their working environment suggesting solutions and novel designs at an earlier stage of the process. Through the coupling of architectural design with parametric modelling methods, the chapter presents techniques that enhance students' learning and knowledge about designing and architectural building processes. This allows a deeper comprehension of the design objectives and aids architectural designers in their decisions to find solutions.

A dilemma of semester-based teaching is that students reach their highest level of skills and experience at the end of a term, after which they leave for their break and are therefore unable to apply their freshly gained knowledge immediately. At the beginning of the next following term, however, the knowledge and skills they had gained earlier are likely to be either inactive or not employed, and learning foci may have shifted to other aims. The architectural design studio presented here addressed these issues by integrating the learning experience from the beginning by focusing on parameters that create or inform about the design. The objective of this 'parametric designing' was to allow students to understand the impact each step and variable has on the design and follow the impact it has onto the project. Students developed

Figure 1. Right: Pieter Bruegel's 'Tower of Babel. Right: Archigram's Plug-in City
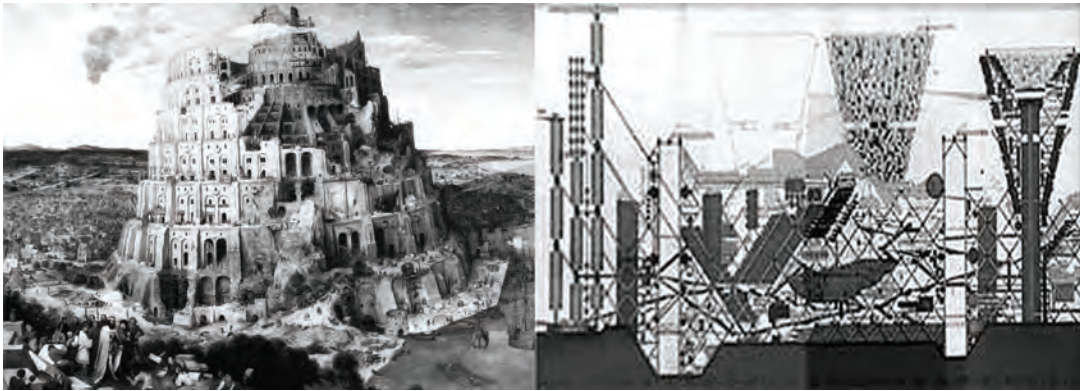
and communicated their design parameters by utilizing their knowledge throughout the design-studio environment. Because of this, students began to think about design problems in different ways. The studio explored design by basing it on parameters and their connecting rules. In order to build up a philosophy around parametric dependencies and relationships, the participants used digital instruments that aided them to create and express their designs. With these instruments, they could develop expertise to engage creatively in designing. The studio cumulated in an architectural art exhibition highlighting the coupling of architectural design with digital modelling and fabrication methods. Students presented architectural solutions that challenged and addressed environmental and programmatic issues, dimension, space and volume, as well as theoretical and conservational topics, resulting in novel designs created with freedom of innovation, interpretation, and definition some of which without any boundaries. The notion of non-conformity added to the core of this collection of works, held together by the idea of spatial concepts and parametric designing in architecture.

BACKGROUND

Pieter Bruegel, a Netherlands' Renaissance painter, depicted a representation of the 'Tower of Babel' as a building that is constantly redefining its needs, as it grows larger and more complex (Figure 1). The painting shows a tower nearly reaching the clouds and illustrates all the problems then associated with cities, buildings and life within and the constant change and reaction to new situations during the process of building.

The exploration of the relationship between human beings and the natural world, and the subsequent implications of interactions between them, has deep roots in our social and cultural understanding of society. Cities, therefore, are direct reflections of their inhabitants, as their architectural expressions directly influence the living conditions of their people. In recent practice, architects have designed and described buildings through the means of (master-) plans, sections, elevations, or descriptions of render-perfect, complete architectures in which change was not part of the picture. A few, however, have tried different approaches to communicate architecture.

In the 1960s and early 1970s, Archigram already presented an idea that reacted against the permanence of houses in what it called the "Plug-in City" (Figure 1, right). They proposed architecture that is ever changing and adaptable to different

social and economic conditions (Karakiewicz, 2004). Their proposal did not develop further than a conceptual stage, yet it lays in contrasts to the common practice that also Le Corbusier describes as non-intelligent building machines, whereby these machines would not think, and would therefore be unable to adapt to change.

More recently 'LAB Architecture Studio' translated planning codes of Beijing's 'Soho Shang-Du' into series of parametric design rules whereby the outcome both complies with and confounds the rigid regulations (Davidson, 2006). As a result, the architects did not prescribe a fixed definition of architecture, but a set of rules and instructions that inform about and can generate the outcome. This allows a reaction on a variety of site-specific variables that can be modified according to the need, yet fit into the overall design intents of the architects.

These samples point out the constant demand for architecture to adapt and react to a variety of parameters that are driven by its use and context. The gap between the architectural design conceptions and the translation of these designs into the real built environment can be addressed fundamentally differently by an intersection of process and outcome (Eastman, 2004). Parametric design and digital fabrication techniques suggest controllable and adaptable solutions at an earlier stage of the process that react to the given situations and the outcomes.

PARAMETRIC DESIGN STUDIO

Architectural design studios are an essential learning experience for architectural students. Their traditions and proceedings are well established. Studios go beyond pure skill training and require reflection upon, and the creation of, knowledge. These studios are, additionally, informed and supplemented by courses and seminars that contribute to the overall learning goals. Yet there can be a gap between skill training and application of knowledge. At the end of the studio, students may not be able to identify how they arrived to their solution and solves a given problem, or what were the individual contributors that made their design successful.

In computational architectural studios, the same phenomena can be observed. These studios present the underlying concepts of architectural design using computational instruments, and have at the same time to provide for software skills and other technical knowledge (Kvan, 2004A). The integration of digital media into design studio curricula often fails, because the compound acquisition of skills prevents a deep exploration of design and the theoretical aspects involved at the same time. Participants can employ computational instruments within a studio context only after they have learned subject matters and acquired proficiency in their skills. By then, the studio may consider these skills no longer valid or has ended.

Parametric applications have inherited two crucial elements. These are that all entities start in a multi-dimensional space and allow the study of architectural conditions in a cloud of data and variety of representations, rather than the conventional two-dimensional or layered design environment. The underlying notion of parametric designing is based on the contextual construction of a formal and spatial systemic intelligent simulation; or in other words data, variables, and their relationship to other entities, which can then respond to variations of necessities (Ambrose, 2009). Students learn about cause and effect in both abstract environments as well as at specific situations of their design task. This is where architectural education is in the process of changing fundamentally. Design studios and courses are now increasingly reacting to the quantum leap architectural computing has presented to design education, and introducing computational parametric tools to the design studios that go beyond Computer Aided Design (CAD) (Picon, 2010). Yet one has to be careful that novel technologies and learning methodologies offer current pedago-

gies to address certain known issues and cannot eliminates all problems connected with learning and education.

PARAMETRIC DESIGNING

Architecture in general can be expressed and specified in a variety of ways. Commonly, drawings describe geometric properties that can explain, depict, and guide the construction of buildings or streets. Alternatively, performance specifications can describe observed behaviours. It is also possible to describe properties as relationships between entities. Spreadsheets, for instance, specify the value of each cell as the result of calculations involving other cell entries. These calculations or descriptions do not have to be explicit. Responsive materials change their properties in reaction to the conditions around them. A thermostat senses air temperature and controls the flow of electric current, and hence the temperature of the air supplied. Using such techniques, artists have created reactive sculptures and architects have made sentient spaces that react to their occupants or other relevant factors. Streetlights turn on if light levels fall below a threshold; traffic flow can be regulated according to need; walls can move as users change location.

Links to a variety of data can be established and subsequently serve as the bases to generate geometric forms using parametric design instruments. When designing spaces, it is usual to collect some data of the type of architectural qualities desired. These are then, for example, translated into master plans, which are themselves specific spatial descriptions. Performance requirements for spaces can then be written, linking the description of the architecture to experiential, financial, environmental, or other factors (Picon, 1997).

Design studios mimic the typical working processes of the architectural profession and are the essential learning experience for architectural students. Research is now looking into how the framing of design problems using parametric methods enhances the overall process (Schnabel et al., 2004). The here presented studio, therefore, couples parametric methodologies within the generation of architectural design, ultimately re-framing the problem and proposing new answers to design thinking and learning. Participants in this study solved a typical architectural design problem using computational applications that focused on the parametric dependencies of spatial entities, generative scripts, and form finding. The re-representation of the design intent sharpens the question at its centre (Gao and Kvan, 2004), while taking full advantage of available parametric modelling software to explore it. This approach tested the limitations set by conventional, design-only methods. The cognitive aspects of the design generation and their relationships to parametric design methods operated as an influential factor for the understanding of the projection of design intent, framing, generation of spatial knowledge within architectural design and the reflection about the outcome produced in this process (Ambrose, 2009).

Problem Framing

The studio engaged the participants in design processes by using sets of variables and series of relations to question, create, and define the form and function of the resulting designs. Thus, the students examined interaction techniques between their design intent, their framing of the design problem, their subsequent generation and reflection on their development by testing the rules and parameters. Participants engaged in a collaborative architectural design studio involving the creation and fabrication of architecture. This formed the basis for a transfer of knowledge to the larger context of the issues ahead in their future professional careers (Riese and Simmons, 2004).

The studio took a distinctive neighbourhood within the larger urban context of Sydney, Australia as its base of exploration. The specific site

Figure 2. Four phases and exhibition of the design studio with learning reflections and projections
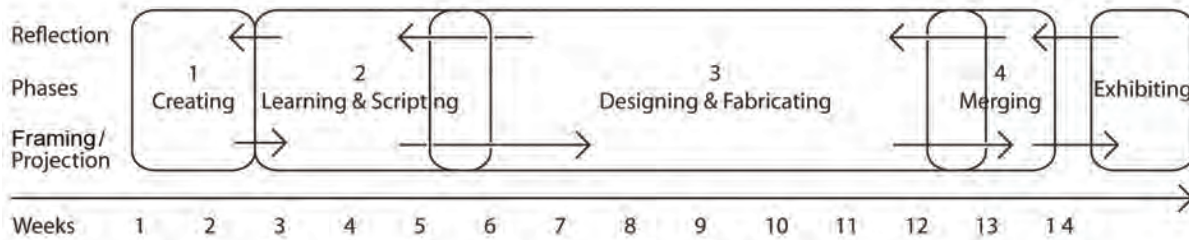
surrounding, a mix of residential, public and commercial buildings, offered a medium dense area with a variety of architectural languages.

Driven by a fast growing population, an architectural strategy that steers further development was sought. The city's scale, its growth through migration and the need for new housing have an impact on its inhabitants' sense of place and sense of community. Earlier urban planning did not anticipate the changes that arose over years of population growth. Hence, a new strategy for development that could address these issues was sought to create a new identity for the place and the city itself (Forrest et al., 2002).

The site of the studio had typical architectural characteristics and requirements. Located at a riverbank, in close proximity of a parkland, cultural-, office- and residential buildings, the site offered a variety of inspiration as well as constrains for an architectural design exercise. Students had to address and responded to the local and overall conditions of open space, city, work, living and environment.

The studio built upon design studios where participants explored design methods and tools beyond their original definitions and perceived limits (Schnabel et al., 2004). To allow the students both to acquire skills and training within their studio and to apply this knowledge to their design, the studio had an integrated digital media component that addressed parametric modelling in architectural design.

Two groups of fifteen students of the postgraduate architectural program each joined this studio, which was guided by two design tutors and one architectural consultant in digital media. The studio was structured in four phases that related to and built upon each other (Figure 2). The aim was to acquire and integrate parametric design knowledge and to use it as the base of the design creation of their architectural proposal. As a result, the final design could be modified and manipulated based on the parameters and their dependencies, allowing the students to gain a deeper understanding of their design processes and outcomes as well as the reaction of their proposals with the various influences of the site.

Creating

The project's first component included the collection and understanding of data that arrived from the site. In order not to overwhelm the students, the tutors asked them during this first stage to limit them to investigating only two points of interests, which became their key-parameters. Hereby the students could focus on the selections of parameters that they believed would influence their building proposal or their site's perception, this parameter could be a real or abstract item (Figure 3).

The parameters they chose informed them about the variables and correlation of their guiding design principles that formed their initial rules. These provided them a description based on de-

Figure 3. Two parameters (floor-heights) used by a student team (R Beson & N Minasian)
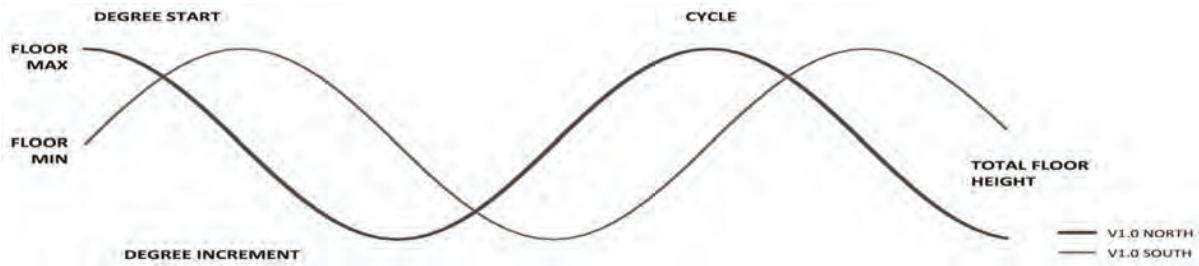
pendencies and interconnected relationships of relevant information. The chosen parameters helped the students to understand what impact certain variables may have on a design strategy and the design itself. This component concluded after two weeks with presentations of data, parameters, and individual interpretations of the site.

Learning

The program's second component focused on the understanding and creation of parametric concepts and the acquisition of design-application skills that allow rule-based three-dimensional design. Participants were trained intensively during studio time in the use of *Digital Project ™* (2004). This software allows users to not only create three-dimensional models, but also to establish rules, create parameters and their dependencies on a variety of entities (Figure 4).

Parametric functions require a different understanding of the conceptual approaches to design. Creating rules and dependencies, which then create the design, involved the students in a higher level of problem framing and definition of the concept of design. It allowed the visualization and modelling of highly complex forms that may result from non-traditional design data, such as noise data or spatial requirements.

The students focused on their own parametric and rule-based design analyses from the first component and subsequently studied mainly only the aspects relevant to these in relation to the use and

operation of the software, the creation of rules, and parametric and generative design. During this phase, they used the time allocated to the design studio to establish a basic understanding of the software in its relationship to the design intent developed during the first phase. After three weeks of intensive training in architectural computing, the students reached a sufficient level of skills that enabled them to use the parametric software as an aid for the creation of their own designs.

Scripting

'Script' is derived from the term for written dialogue in the performing arts, where actors are given directions to perform or interpret. Subsequently, 'scripting' is a creative process that describes the artistic intent of the designer. Scripts can define a set of rules that combines parameters in the named way. Software applications can be programmed and adjusted by scripts allowing for example repetitive tasks to be automated or to generate solutions that fit to a range of parameters (Biloria et al., 2005). Instead of using only compositional methods for designing, the students utilized scripts to form their own generative properties and base for their design exploration (Figure 5). Sourcing related or suitable general available scripts students quickly learned how to edit and control their design by amending the parameters or rules to fit their design intent (Celani, 2008). This phase differs greatly from conventional studios because students are engaging in software training and skill

Figure 4. Development of parameters, dependencies and rules within software analogue (left) and digitally (right) (Beson & Minasian)
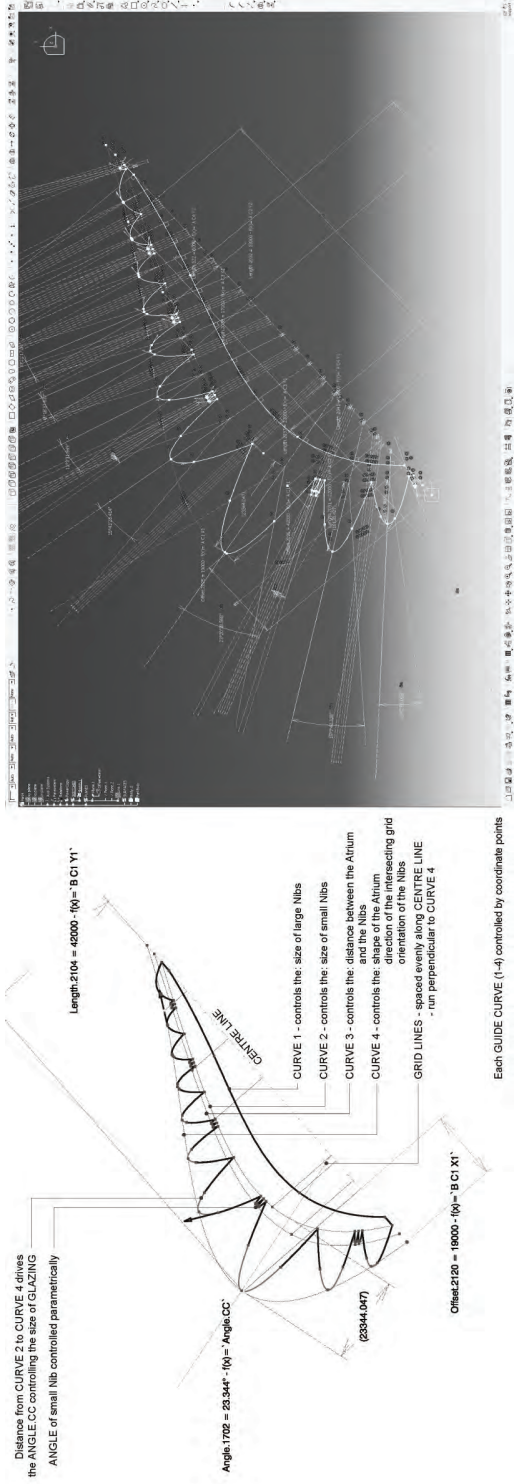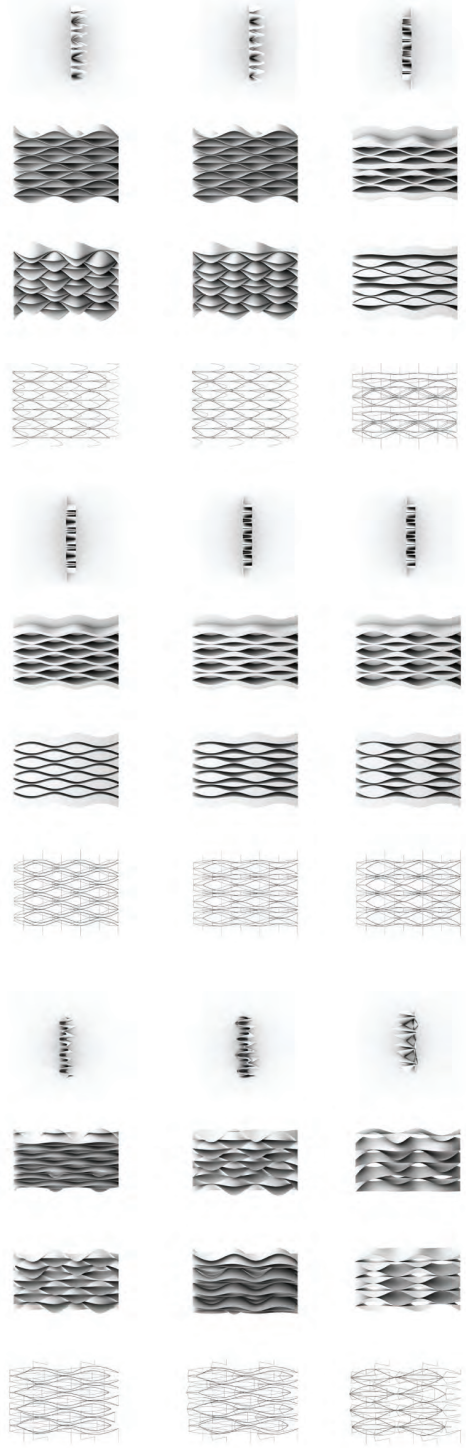
Distance from CURVE 2 to CURVE 4 drives
the ANGLE.CC controlling the size of GLAZING

ANGLE of small Nib controlled parametrically

Length:2104 = 42000 - f(x)= 'B C1 Y1'

CENTRE LINE

CURVE 1 - controls the: size of large Nibs

CURVE 2 - controls the: size of small Nibs

CURVE 3 - controls the: distance between the Atrium
and the Nibs

CURVE 4 - controls the: shape of the Atrium
direction of the intersecting grid
orientation of the Nibs

GRID LINES - spaced evenly along CENTRE LINE
- run perpendicular to CURVE 4

Each GUIDE CURVE (1-4) controlled by coordinate points

(23344.047)

Offset.2120 = 19000 - f(x)= 'B C1 X1'

Angle.1702 = 23.344° - f(x)= 'Angle.CC'

Figure 5. Variations generated by a script to modify facade-tiles (Beson & Minasian).

62

acquisitions of how to generate and manipulate instructions for computer programmes that can aid their design process.

Designing

The program's third component, scheduled for seven weeks, concentrated on design creation, reflection, and the communication of architectural design proposals. Using the data of the first component and the skills of the second, the students then started to establish and visualize their designs in three-dimensional forms that created spatial expressions of their findings and explorations.

Due to the emphasis on parameters, the studio was in particular interested in describing a building form by creating dependencies of parameters that defined the relationship of data to architectural expressions. With the use of a parametric modeller, it was easy to create geometric entities, solids and voids, and relate them to the context of the design task. This method made it obvious how one can learn about design and understand the various steps and elements through the logical steps laid out by the chosen parameters, variables, rules or scripts.

Fabricating

Another stage in the creative process is the fabrication of the digitally created designs. Recent computational applications and digital fabrication technologies have allowed architecture to take novel directions. The combination of architectural computation with computer-controlled machinery has nearly made it possible for shapes, however complex or irregular they seem to be, to be rationalized and created as physical entities with the ultimate aim to result in a buildable architecture (Oxman and Oxman, 2010). The studio subsequently made extensive use at all stages to explore the transformation of virtual design conceptions to physical objects via the use of computer-aided manufacturing (Figure 6).

Merging

The program's next following component brought together the various aspects and results of the earlier modules. Within two weeks, the students merged their individual designs into larger cluster files. This synthesis created compound descriptions and dependencies that were highly complex and interrelated, yet both the content as well as the tool allowed seamless communication to a larger

Figure 6. Facade details from the digital model fabricated by rapid-prototyping (Beson & Minasian)

Figure 7. A joint model that combined facade, interior spaces and atrium details
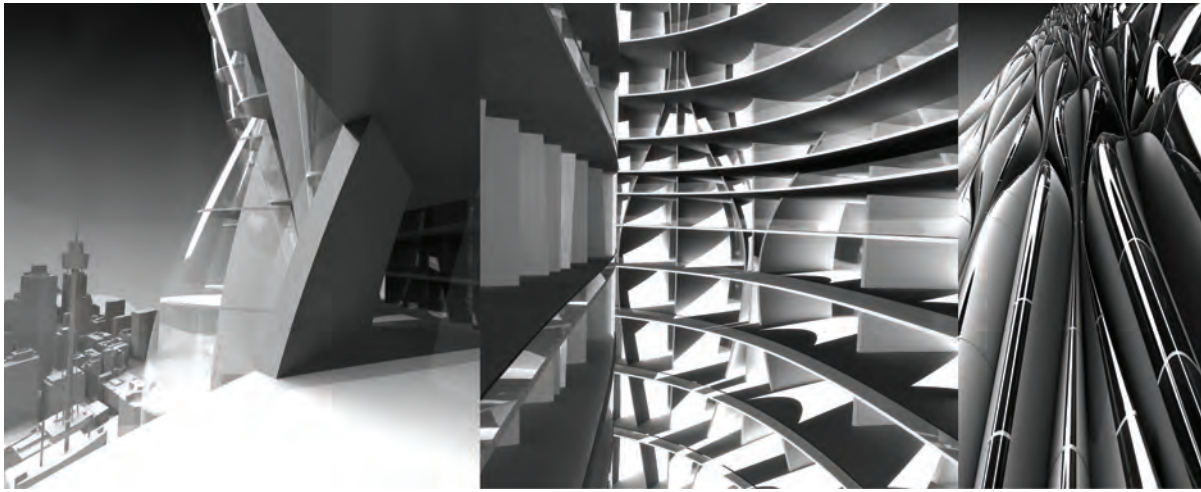
audience by describing the rules and parameters (Figure 7). This phase created a design with shared authorship of all participants and allowed the students to study and understand the complexity and the interrelationships of architectural designing that they normally would have been unable to perceive immediately. Through their collaboration and exchange the students built up a collective intelligence that was driven by the individual contributions. The change of a single variable modified the whole design. Participants understood therefore the complex dependencies that one variable has in a large building and the impact it can have on the design.

Exhibiting

The design explorations culminated in an exhibition displaying the designers' engagement with parametric designing and fabrication (Figure 8). To mark the distinctive final stage in a celebrative conclusion of design development, the event

Figure 8. Exhibition of final designs at Brand Smart Centre (left) & Tin Shed Gallery, Sydney (right)

exemplified how digital architectural design can conceptually and artistically engage with a particular site, where a variety of solutions to problems in architectural design were developed from a diversity of multi-faceted and eccentric approaches (Schnabel and Bowller, 2007). The participating designers pushed creativity to new boundaries in definition of their artwork and cultural contexts, setting the direction for poetic viewpoints on innovation in architecture and spatial design. The exhibition forms a crucial learning experience whereby both processes and outcomes are presented in a formal way that is self-explanatory to a wider audience.

The compiling of all projects into a single exhibition removed the designers from the context of individual ownership, providing them with the invaluable opportunity to reflect on both, their own and their colleagues' proposals as a coherent collection of contributions towards one common engagement of design.

OUTCOMES

Participants of the parametric design studio were able to employ digital media skills from very early on throughout the studio and expand on these with their understanding and communication of design issues from there.

The students had already acquired a very high level of skills in using a specific parametric instrument within the first half of the studio. This enabled them to employ the instrument as an amplifier to learn about their designs. Subsequently, they were not limited by their knowledge or level of skills in order to be able to express themselves. The students produced a variety of individual design proposals as well as one large design-cluster. They created rules, scripts and parameters that allowed complex and interrelating designs to emerge. These representations could not be generated or communicated using traditional architectural design methods or instruments.

For example, one proposal related street lighting, neon-signs and display-windows with human activity around the building site. These parameters provided the engaging surface for the building mass. Subsequently they controlled the use, orientation and appearance of the building. The author took references to Japanese inner cities, where innovative ways of spaces are created by the means of lights, advertising and projections. Void, volume and density is controlled and created by the rhythm and intensity of lights. The student transferred this concept into parameters, which redefined the spatial understanding of the site and used these variables to create an architectural proposal.

Other results used parameters that related to the relationships between people and attraction to spaces with responsive structures. Students created self-opening canopies that reacted to people, activities, ferry schedules, weather conditions and the possibilities to collect rainwater to provide a comfortable environment in all conditions. One team reacted with different floor-heights to various needs of public and private programme of their building and related their spaces to vista and light penetration of their building (Figures 3-6). These explorations then were merged with parameters controlling the interior space, atrium and program to form an overall design of a mix use building (Figure 7).

In the studio's last component, all students presented in-depth clusters of multifaceted architectural design proposals for the site. They demonstrated a high level of thinking processes resulting in the generation of compound rules and dependencies that finally create the architectural design schemes. Each student contributed simultaneously to create a variety of design proposals. The participants gained a high level of expertise with digital parametric tools as part of their development at the studio, and used this knowledge to design parametrically. The outcome clearly showed that thinking, learning and creating within parametric designing requires a novel and deeper

understanding of the overall design goal and its anticipated outcome. The studio also showed that a social engagement with team members created a common knowledge to which everyone not only contributed but also benefitted. Students subsequently build up a social intelligence that allowed them to address both skills and design problems.

Students reported of the step learning curve of understanding how parametric software is structured differently to conventional software. They reported that they could not just design intuitively as they would do in conventional studios and had to stick to the rigour process of the parametric design methodology. The skill training in the software and the translation of the design intent proved not always to be straight forward. Some students only gained the full understanding of the potential parametric modelling offers at the end of the studio where all solutions were presented. While others had difficulties in developing a logic string of design steps that relate to the parametric approach, they preferred or felt back to intuitive or conventional designing.

Parametric modelling subsequently does not solve all issues connected with design-learning. It allows however, an alignment of cause and effect and a reflection of the design intent, the process and outcome. This differs from conventional design studios where these dependencies only seldom can be established. The studio allowed participants to learn about designing and problem framing. They were able to theorize and reflect on design creation for this and other design tasks. Consequently students engaged in a deeper learning that allows them to transfer and adapt their knowledge to new situations. Results can be explored at: www.parramatta.tk and www. disparallelspaces.tk.

DISCUSSION

In the early stages of computational architecture, designing in layers was a popular enrichment to conventional designing because it allowed architects to deal with problems that are more complex, with each different layer playing a specific role. It singled out issues and allowed dealing with them one at a time. Items that are more complex were divided into separate issues and dealt with one by one. Parametric design opens up a novel set of opportunities. It enables architects to study causes of problems and their relationships to, and dependencies on, other elements directly within a three-dimensional environment.

This shift of design thinking and creation needs to be addressed in the teaching and learning of design. Additionally, parametric designing provide for unpredictable events in connection with an overall architectural framework. Architects and architecture itself can respond to unplanned changes and their resulting consequences. The outcomes of this design studio showed that parametric dependencies allowed for such a level of ambiguity that is desired and required in creative and learning environments.

One objective of the studio was to frame an intellectual question that created design descriptions based on rules, scripts and parameters. The more interesting outcomes resulted from the ability to redefine and reframe the problems themselves by stepping out of preconceptions based on experience and exploring sets of unpredictable answers and then reflecting back on the starting point. Hence, in certain ways, parametric designing act at a higher level of the problem framing. The establishment of meta-rules has instituted a form of problem framing that demands the reference of one problem or parameter with other ones.

The learning outcomes of the parametric design studio demonstrate how non-linear design processes led to architectural design understandings that differ from conventional approaches to design learning due to their different nature of design thinking, framing, creation, and intuition. Despite three-dimensional representations of an architectural space being only a medium aiding the understanding and communication of spatial

arrangements, the designers' comprehension of complex spatial qualities was enhanced by the parametric design environment, partly due to the logic structure and dependencies of one step to the next. The steep learning curve and the time needed to adjust to the parametric and sometimes stringent or seemingly limiting methodology of parametric designing shows that conventional designing is the pre-dominant approach to design and deeply routed in the design-thinking of students. Yet despite these difficulties students unanimously reported that the here presented studio helped to understand how to design and they highly valued the approach to thinking about and executing designing.

The use of parametric instruments allowed all students to design within an environment based on rules and generative descriptions, amplifying their understandings of creative processes and their learning outcomes. Each designer bridged the rift between their knowledge and ambition, creating architectural designs and learning about the act of architectural designing.

NEXT STEPS

The increasing marginalization of architects in the building industries (Bennetts, 2008) suggests that professional and educational ideals and professional work are poorly aligned. Unlike other professions, architects are trained in a variety of fields of knowledge and skills that are not directly related to the daily routine of the architectural praxis. Subsequently architecture students have an increasing amount to learn following graduation. Architects have discovered how digital instruments alter any aspects of their routines of working. However, academic and educational environments are not able to follow in the same speed. Learning designing has shifted from the single learner to a collective engagement with a variety of learners, novices, experts and instruments that aid, analyze, generate, design and

review. Less than a decade ago many schools of architecture did not allow students to deliver CAD drawings for design projects assuming that would limit the exploration and understanding of design. In fact, the early experiments in using the computer in the design process quite often failed only because of the restrictions of the available infrastructure, facilities and skills. Today, students are familiar with architectural computing even before they enter the university (Dokonal and Hirschberg, 2003).

Still many questions remain unanswered and new questions arise in the relationship between architectural design and architectural computing. Architectural design is both an imagination and the ability to convey this idea. The learning of architectural design has to make use of the advantages that complex architectural computing offers without loosing the qualities of the established conventional methods. The current 'Net-Generation' (Oblinger and Oblinger, 2005) of learners, who are more conversant in using computational instruments than their teachers, are changing the dynamics of architectural education. This is a challenge to established curricula and institutions.

The herein presented studio is a successful attempt to integrate architectural computing into the learning environment by aligning skills and knowledge of the students with the objective to generate knowledge about designing, computation, architecture and realization.

Akin to Maver's (1995) comments, parametric designing and for that matter, architectural computing is certainly far from being resolved and offering the perfect solution. As the needs, goals and problems are rapidly developing architectural design and its learning needs to facilitate the evolution and progress. Synergies between the different realms, media and technologies are constantly evolving and adjusted to foster the evolution of architectural praxis and the building industry (Eastman et al, 2008).

CONCLUSION

The parametric design studio method presented in this chapter addressed computational concepts of architectural designing that influence the recent learning environment of architectural education. It coupled the setting of studio-learning with an in-depth digital media training in order to close the gap between acquisition of skills and the re-flection of knowledge, as well as to explore new avenues of framing and integrating compound design issues. The use of digital parametric instru-ments allowed the participants to design within an environment based on rules and generative de-scriptions, amplifying their design understanding and their own learning. The students connected their knowledge with their ambition to create their own design proposals.

The synthesis of all individual projects re-moved the students from individual ownership of their designs, but allowed them to reflect on both their own and their colleagues' designs as a complete cluster of contributions (Kvan, 2004B). This related to earlier research into design studios based on the same principle, in which media were applied outside their normal pre-described purposes, and innovative design methods were deployed by interplaying digital media and design explorations (Schnabel et al., 2004).

With the employment of parametric design methods that allowed students to experience the dependencies and rules of the various individual contributions spatially, as well as the overall com-mon proposals, the design was communicated using digitally controlled manufacturing processes and digital representations.

The studio was phased in such a way that each section built upon the next and became an essential part of the overall design learning and creation. They addressed and expressed certain aspects of the process. A holistic discussion about design, form, function, and development is consequently established - a significant venture not only within the architectural realm, but also in all other dia-logues involving spatial representation.

REFERENCES

Ambrose, M. A. (2009). BIM and comprehensive design studio education. In *Proceedings of the 14th International Conference on Computer Aided Architectural Design Research in Asia* (pp. 757-760). Yunlin, Taiwan: CAADRIA.

Bennetts, R. (2008). Reasserting the architect's position in pursuit of sustainability. In S. Roaf & A. Bairstow (Eds.), *The Oxford Conference: A re-evaluation of education in architecture* (pp. 11-16). Southampton, UK: WIT Press.

Biloria, N., Oosterhuis, K., & Aalbers, C. (2005). Design informatics. In *Smart Architecture: Inte-gration of Digital and Building Technologies* (pp. 226–235). Savannah, GA: ACADIA.

Celani, M. G. C. (2008). Teaching programming to architecture students. *Revista Gestão & Tec-nologia de Projetos*, *3*(2), 1–23.

Davidson, P. (2006). *The regular complex*. Paper presented at the NSK Wolfram Science Confer-ence, Washington, DC. Retrieved May 10, 2010, from http://www.wolframscience.com/confer-ence/ 2006/presentations/davidson.html

(2004). *Digital Project* ™. Los Angeles, Califor-nia: Gehry Technologies.

Dokonal, W., & Hirschberg, U. (Eds.). (2003). *Digital design*. Graz, Austria: eCAADe and Graz University of Technology.

Eastman, C. (2004). New methods of architec-ture and building. In *Fabrication: Examining the Digital Practice of Architecture* (pp. 20–27). Cambridge, Canada: ACADIA & AIA Technology in Architectural Practice Knowledge Community.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. New Jersey: John Wiley & Sons.

Forrest, R., La Grange, A., & Yip, N.-m. (2002). Neighborhood in a high rise, high density city: Some observations on contemporary Hong Kong. *The Sociological Review*, *50*(2), 215–240. doi:10.1111/1467-954X.00364

Gao, S., & Kvan, T. (2004). An analysis of problem framing in multiple settings. In Gero, J. (Ed.), *Design computing and cognition* (pp. 117–134). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Karakiewicz, J. (2004). City as a megastructure. In Jenks, M., & Dempsey, N. (Eds.), *Future forms for sustainable cities* (pp. 137–151). Oxford, UK: Architectural Press.

Kvan, T. (2004A). Collaborative design: What is it? *Automation in Construction*, *9*(4), 409–415. doi:10.1016/S0926-5805(99)00025-4

Kvan, T. (2004B). Reasons to stop teaching CAAD. In Chiu, M.-L. (Ed.), *Digital design education* (pp. 66–81). Taipei, Taiwan: Garden City Publishing.

Maver, T. W. (1995). CAAD's seven deadly sins. In M. Tan & R. The (Eds.), *The Global Design Studio, Proceedings CAAD Futures* (pp. 21-22). Singapore: Centre for Advanced Studies in Architecture, National University of Singapore.

Monedero, J. (2000). Parametric design: A review and some experiences. *Automation in Construction*, *9*(4), 369–377. doi:10.1016/S0926-5805(99)00020-5

Oblinger, D. G., & Oblinger, J. L. (Eds.). (2005). *Educating the Net generation*. Washington, DC: Educause.

Oxman, R., & Oxman, R. (Eds.). (2010). Special issue: The new structuralism: Design, engineering and architectural technologies/ *Architectural Design, 80*(4).

Picon, A. (1997). Les annales de la recherche urbaine. *Le Temps du Cyborg dans la Ville Territoire, 77*, 72-77.

Picon, A. (2010). *Digital culture in architecture: An introduction for the design professions*. Basel, Switzerland: Birkhäuser.

Riese, M., & Simmons, M. (2004). The glass office - SCL office and showroom in Brisbane, Australia. In *Fabrication: Examining the digital practice of architecture* (pp. 28–33). Cambridge, Canada: ACADIA & AIA Technology in Architectural Practice Knowledge Community.

Schnabel, M. A., & Bowller, N. (Eds.). (2007). *Disparallel spaces*. Sydney, Australia: The University of Sydney.

Schnabel, M. A., Kvan, T., Kuan, S. K. S. & Li, W. (2004). 3D crossover: Exploring - Objets digitalise. *International Journal of Architectural Computing – IJAC, 2*(4), 475-490.

ADDITIONAL READING

Derix, C. (2009). In-Between Architecture Computation. *International Journal of Architectural Computing – IJAC, 7*(4), 565-586.

Iwamoto, I. (2009). *Digital Fabrications: Architectural and Material Techniques*. New York: Princeton Architectural Press.

Jones, C., Ramanau, R., Cross, S., & Healing, G. (2010). Net generation or Digital Natives: Is there a distinct new generation entering university? *Computers & Education*, *54*(3), 722–732. doi:10.1016/j.compedu.2009.09.022

Karakiewicz, J., Shelton, B., & Kvan, T. (2010). *From Vertical to Volumetric: prototypical Hong Kong*. Routledge.

Rahim, A., & Jamelle, H. (Eds.). (2007). *Elegance-Architectural Design AD. 77(1)*. London: John Wiley & Sons Ltd.

Schumacher, P. (2010). *The Autopoiesis of Architecture*. London: John Wiley & Sons Ltd.

Sterk, T., & Loveridge, R. (Eds.). (2009). *reForm() Proceedings of the 29th annual conference of the Association for Computer Aided Design in Architecture*. Chicago, Illinois: ACADIA

Tidafi, T., & Dorta, T. (Eds.). (2009). *Joining Languages, Cultures and Visions/Joindre Langages, Cultures et Visions - CAADFutures 2009*. Montréal, Canada: Les Presses de l'Université de Montréal.

Wang, X., & Schnabel, M. A. (Eds.). (2009). *Mixed Reality Applications in Architecture, Design, and Construction*. Amsterdam, Netherlands: Springer-Verlag. doi:10.1007/978-1-4020-9088-2

KEY TERMS AND DEFINITIONS

Architectural Computing: Architecture that is aided or generated by computational means.

Computational Architecture: Architecture and its design that arrived from or in collaboration with computational means, instruments or aids.

Design Education: The pedagogical approach to teach and learn to design.

Design Learning: Learning of how to design with the aim to become a good designer.

Design Process: The elements that contribute to the making of a design.

Parametric Designing: Designing using a parametric methodology that employs parameters, rules, and systems.

Parametric Design Studio: Design Studio that employs parametric designing as core method of enquiry.